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Short Communication

First data on uranium uptake in three nototheniid fishes from Antarctica (James Ross Island)

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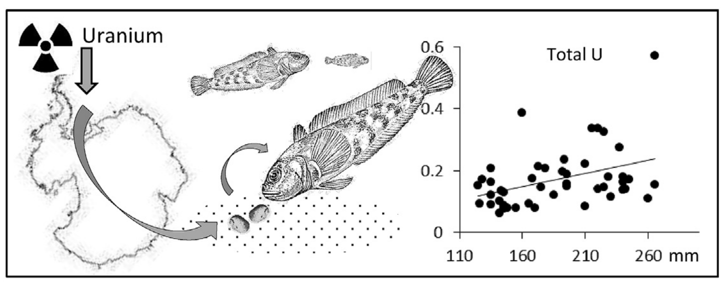
HIGHLIGHTS

- First quantitative baseline uranium levels presented for Antarctic nototheniids.
- Levels low but emerald rockcod show evidence of bioaccumulation.
- Bioaccumulation linked with dietary specialisation on molluscs?
- Possible links with atmospheric deposition and climate change.
- In depth trophic studies needed on Antarctic food-web dynamics.

GRAPHICAL ABSTRACT



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ABSTRACT

Recent studies have confirmed historic atmospheric deposition of uranium in Antarctica, with a steep and significant increase in levels deposited since the 1980s in Antarctic Peninsula ice core samples. To date, however, there has been little or no attention paid to uranium in the Antarctic food web. Here, we present results for uranium content in scales of three common nototheniid species (*Trematomus bernacchii*, *Gobionotothen gibberifrons*, *Notothenia coriiceps*) from coastal waters off James Ross Island (Antarctic Peninsula). While mean total uranium levels (mean ± SD) were low and similar between species (*N. coriiceps* 0.08 $\mu g\,g^{-1} \pm 0.01$, *T. bernacchii* 0.17 $\mu g\,g^{-1} \pm 0.10$; *G. gibberifrons* 0.11 $\mu g\,g^{-1} \pm 0.04$), linear regressions against standard length indicated bioaccumulation in *T. bernacchii* (ANOVA, $F = 7.8349$, $P = 0.0076$). We suggest this may be the result of dietary specialisation on prey with calcareous shells that accumulate uranium. To the best of our knowledge, this paper provides the first quantitative baseline data on uranium levels in coastal Antarctic nototheniids. While the low levels recorded are unlikely to represent a threat within the food chain, we suggest that further long-term trophic studies (including stable isotope analysis) are needed, recognising that the feeding ecology of individual species (and even individuals) can have a strong effect on overall trends.

1. Introduction

A number of recent studies have noted a worrying increase in the level of uranium in Antarctic snow and ice cores (e.g. Planchon et al., 2002a, 2002b). Most recently, Potocki et al. (2016), using ice core data from the northern tip of the Antarctic Peninsula (see

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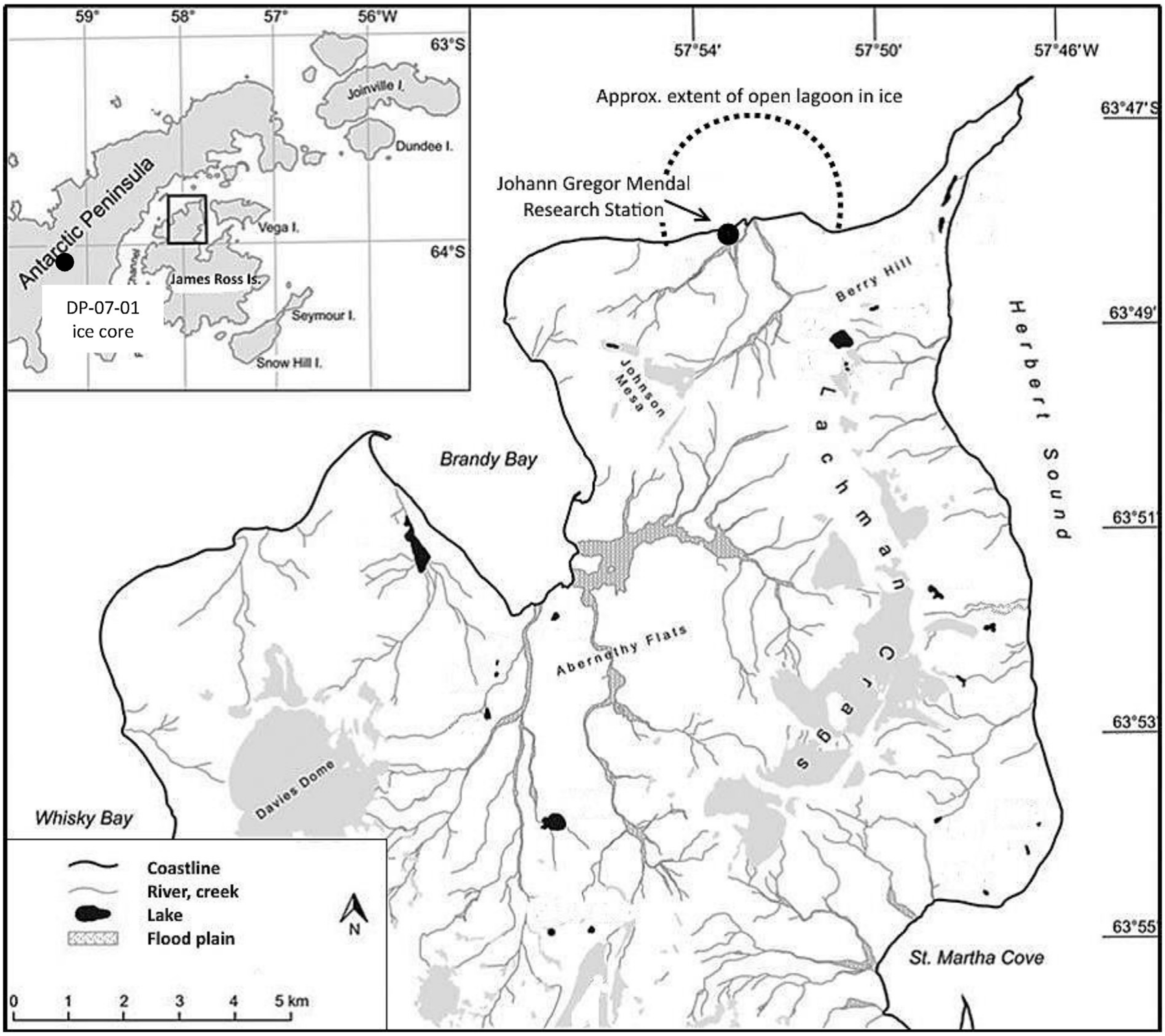

Fig. 1. Position of the Johann Gregor Mendel Polar Research Station on James Ross Island, The black dot in the insert indicates the approximate position of the DP-07-01 ice core on Detroit Plateau, northern Antarctic Peninsula (see Potocki et al., 2016).

Fig. 1), was able to show that there has been a steep and significant increase in atmospheric deposition of uranium over the Peninsula since the 1980s, with Australian mining operations the most likely source. In doing so, the authors stressed the need to assess the impacts of uranium exposure on Antarctic ecosystems, and an urgent requirement for baseline studies into the distribution of anthropogenic pollutants on ecosystem health (Potocki et al., 2016). This is of particular importance given the likelihood of increased meltwater run-off as temperatures and precipitation around the Peninsula increase due to climate change (Park et al., 1998; Simões et al. 1999, 2004; Thomas et al., 2004).

While different heavy metals are known to accumulate more in certain organs than others (e.g. Bustamante et al., 2003), a number of studies have shown that mineralised tissues, e.g. scales and bones, accumulate highest concentrations of uranium in a dose- and duration-dependent manner, particularly at low concentrations, making them the most sensitive indicators of environmental uranium exposure (Cooley et al., 2000; Cooley and Klaverkamp, 2000; Kraemer and Evans, 2012).

Here, we present data on uranium uptake in scales of three nototheniid fishes from coastal waters around James Ross Island (Antarctic Peninsula). By comparing individual uranium concentrations with fish standard length, we also assess whether there is any evidence for bioaccumulation.

2. Material and methods

2.1. Study site

James Ross Island (S 64°6.81967′, W 57°36.44228; 2600 km^2) is situated in the north-western sector of the Weddell Sea, close to the northern tip of the Antarctic Peninsula. The Czech Johann Gregor Mendel Antarctic Research Station (S 63°48.04823′, W 57°52.98268′; Fig. 1) has been located on the island since 2006 and human presence on the island is limited to seasonal visits by a small number of researchers. Power at the station is provided by solar and wind generators, with gasoline only used for emergency generator use. The island's climate is characterised by short summers (December–February) with mean air temperatures often higher than 0 °C, at which time the pack ice usually breaks up along the coast. Coastal substrate consists almost entirely of eroding rock, pebbles, gravel and sand, with no obvious organic sediment.

2.2. Fish sampling

The fish for this study were all sampled during mid-to late February 2014 from the Bohemian Creek estuary (Fig. 1). All fish were sampled using 3 m × 30 m Nordic gill nets (12 panels ranging in mesh size from 5 to 55 mm), set parallel to the shoreline and exposed for 12 h each day between 19:00 and 07:00 in a relatively large area of open water maintained by freshwater stream outflow. Each fish was measured to the nearest 1 mm, weighed to the nearest 0.01 g and aged via scale annuli (see Supplementary Table 1). Three nototheniid species dominated the catch, emerald rockcod *Trematomus bernacchii*, humped rockcod *Gobionotothen gibberifrons* and black rockcod *Notothenia coriiceps* (for a detailed description of sampling methodology and assemblage structure, see Jurajda at al. 2016). Scales for heavy metals analysis (the research group had neither the capacity nor relevant permissions to transport organ samples) were taken from each fish and stored dry in paper envelopes for transport back to the Czech Republic, where they were subsequently stored at −20 °C at Masaryk University (Brno) until analysed.

2.3. Chemical and statistical analysis

Fish scales were washed with deionised water for 40 min in an ultrasonic bath and then air dried in a dust free environment. Content of total uranium was determined using an Agilent 7700× inductively coupled plasma mass spectrometer (ICP-MS) following sample digestion with nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) at 70 °C for 2 h in a Stuart SBH 200D/3 block heater. ICP-MS measurements were carried out in He collision mode for reduction of polyatomic interference from the sample matrix. An internal standard (^{209}Bi) was applied for diminution of matrix effects and signal drift. The methodology was validated through analysis of identical scales (scales from the same fish sample) spiked with a known amount of uranium as there is no commercially available reference material certified for uranium content with a matrix similar to fish scales. Recovery of spiked samples ranged between 96.9 and 100.1% (median 97.7% ± 1.6 SD). Typical relative standard deviations for replicate analyses were within single percentage points.

Simple linear regressions of total uranium (μg g^{-1}) against fish standard length (SL) were applied to each species to assess whether uranium content increased with fish size (analogous with fish age) as a possible indicator of bioaccumulation. Normality was assessed visually. Due to the high level of variation in the results, analysis of variance (ANOVA) was undertaken to confirm slope validity (see Supplementary Table 2 for raw data). All statistical analyses were undertaken using Microsoft Excel 2010.

3. Results and discussion

The mean total uranium level (±SD; range) in scales of *N. coriiceps* was 0.08 μg g^{-1} (±0.01; 0.06–0.11), 0.17 μg g^{-1} (±0.10; 0.06–0.57) for *T. bernacchii* and 0.11 μg g^{-1} (±0.04; 0.06–0.23) for *G. gibberifrons*. Linear regressions indicated no increase in uranium with size (analogous with age) for *N. coriiceps* ($R^2 = 0.0005$; ANOVA $F = 0.4804$, $P = 0.4959$; est. age 4–6 yrs; Fig. 2A), though the sample size for this species was relatively small ($N = 12$). For *G. gibberifrons* (Fig. 2C), there was a slight increase in uranium levels between 174 and 295 mm SL (est. age 3–8 yrs, $N = 46$), though the slope was non-significant ($R^2 = 0.018$; ANOVA $F = 0.1720$, $P = 0.6809$). For both species, levels varied only slightly around 0.1 μg g^{-1}, with just one specimen of *G. gibberifrons* reaching 0.23 μg g^{-1} (Fig. 2C). In comparison, the regression for *T. bernacchii* (Fig. 2B) showed a distinct increase in mean uranium levels

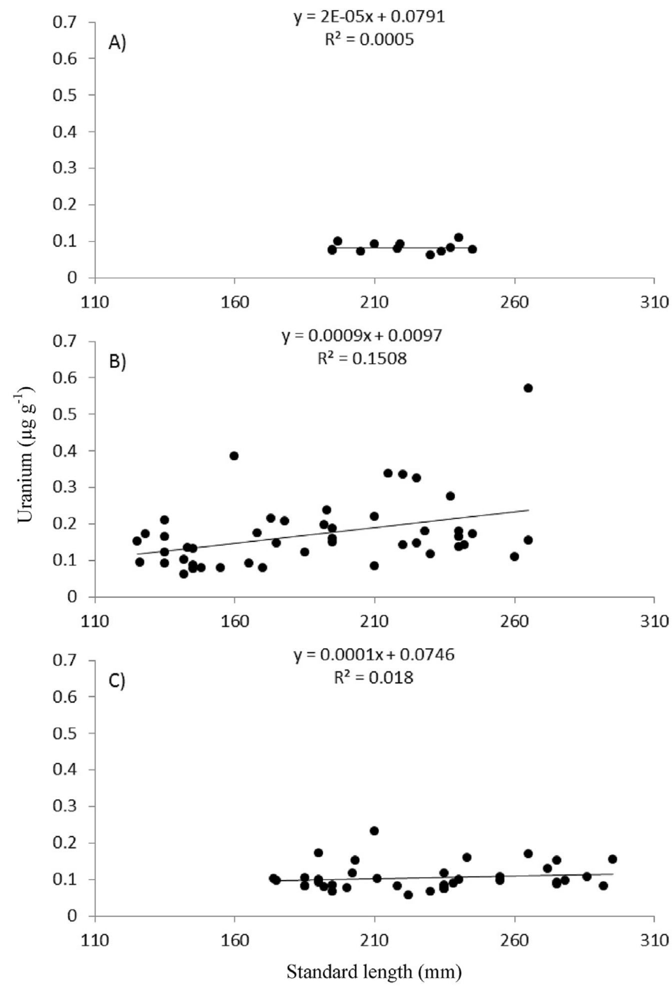

Fig. 2. Linear regressions for uranium concentration in scales (μg g^{-1}) against fish standard length (SL) for A) black rockcod *Notothenia coriiceps*, B) emerald rockcod *Trematomus bernacchii*, C) humped rockcod *Gobionotothen gibberifrons*. Raw data presented in Supplementary Table 2.

between 125 and 265 mm SL (est. age 3–7 yrs, $N = 38$). Though the R^2 value for the slope was relatively low ($R^2 = 0.1508$) due to the high degree of variation, ANOVA confirmed the slope as highly significant ($F = 7.8349$, $P = 0.0076$). While removal of two ‘outliers’ (0.386 and 0.572 μg g^{-1}; Fig. 2B) increased the R^2 value ($R^2 = 0.2135$) and lowered the level of significance somewhat ($F = 6.7202$, $P = 0.0132$), the upward trend remained unchanged.

Natural deposits of uranium do occur in Antarctica; however, these are mainly located on the eastern part of the continent, with no known deposits on the Antarctic Peninsula (U.S. Dept. of State, 1982). Other sources of uranium include input from geothermal activity and, especially, anthropogenic input through wet and dry atmospheric deposition from mining and industrial activity (Bargagli, 2000; Planchon et al., 2002a; Vallelonga et al., 2004). To the best of our knowledge, there are no anthropogenic sources of uranium on the Peninsula. After entering the ocean, uranium is rapidly dispersed and mean surface-water uranium levels around the Antarctic Peninsula (Drake Passage; 3.1 μg/l^{-1}) are similar to those in other parts of the world, e.g. 3.3 μg/l^{-1} around Tierra del Fuego (Sugimura et al., 1964). Uranium may also be bound to organic sediments at concentrations similar to those found in the earth's crust, i.e. approx. 3 mg/kg^{-1} (IRSN, 2001). Hence, aquatic organisms, including fish, are exposed to uranium through

sediment, ambient water and food, though the relative importance of these routes is not always clear (Kraemer and Evans, 2012).

As there is little or no organic sediment along the coast of James Ross Island (P. Jurajda; personal observation), and the levels recorded in scales were considerably lower than those for ambient water, diet would appear to be the main uranium source for the fish in this study. Diet is known to play an important role in uptake of many non-essential metals (e.g. Pickhardt et al., 2006; Deheyn et al., 2005), and Kraemer and Evans (2012) have also demonstrated that feeding ecology plays an important role in determining the degree of uranium bioaccumulation in different species, with benthic species taking invertebrates accumulating considerably more than pelagic piscivores. While all three species monitored in this study are essentially benthic feeders (DeWitt et al., 1990), *T. bernacchii* specialised more on isopods and gastropods than *G. gibberifrons* (see Jurajda et al., 2016; Supplementary Table 3). Just as uranium is known to accumulate in the bones and scales of fish (Cooley et al., 2000), it also accumulates in the carapaces of aquatic invertebrates (Kraemer and Evans, 2012), and especially in the calcareous shells of molluscs (Alìyev and Sari, 2003). As gastropods and molluscs are essentially sediment feeders, uranium levels may be further enhanced by organic sediments present in the gut (Kraemer and Evans, 2012). While molluscs were not often recorded in the diet of nototheniid species in the shallow waters off James Ross Island (Jurajda et al., 2016; Supplementary Table 3), *T. bernacchii*, unlike most nototheniid fishes, show distinct ecomorphological traits indicating dietary specialisation on molluscs (Carlig et al., 2018). Dell'Acqua et al. (2017), for example, recorded *T. bernacchii* specialising on scallops *Adamussium colbeki* in Terra Nova Bay (Ross Sea). As *T. bernacchii* can change their feeding ecology in relation to seasonal changes in coastal pack-ice formation (McMullin et al., 2017), it is possible that molluscs form a greater part of the diet during the Antarctic winter. Further studies would be needed to confirm this, including stable isotope studies to assess seasonal changes in food web dynamics.

To the best of our knowledge, there have been no previous studies on uranium bioaccumulation in coastal Antarctic fishes. As such, the results presented here for three nototheniid species can be taken as baseline levels for future studies. As uranium is not assimilated through successive trophic levels (Kraemer and Evans, 2012; Swanson, 1985), the relatively low levels recorded in our study are unlikely to represent any present threat in the food chain. However, in light of the recent findings of increasing atmospheric uranium deposition over the Peninsula (Potocki et al., 2016) and the likelihood of increased meltwater run-off as temperatures and precipitation around the Peninsula increase due to climate change (Park et al., 1998; Simões et al. 1999, 2004; Thomas et al., 2004), we suggest that levels accumulated in the food chain could increase in the future, with possible intra- and interspecific impacts on the delicate Antarctic food web. As such, there is a clear need for long-term monitoring studies on coastal Antarctic food webs, recognising that the feeding ecology of individual species (and even individuals) can have a strong effect on overall trends.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.chemosphere.2018.07.195.

Statement

The funding sources had no involvement in the study design, sample collection, analysis or interpretation of the data, writing of the report or in the decision to submit the article for publication.

Declarations of interest

None.

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